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Fatigue behavior of **Dual-Phase** and **TWIP** steels for **lightweight automotive structures**

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Overall aims

- To characterize and compare mass-produced (*Dual Phase*), innovative (*TWIP*), and experimental high strength steels for car weight reduction
- To facilitate the industrialization of these new steels, with regards to both **production processes** and **service requirements**
- To study these steels **fatigue crack growth behavior**, which may in future be considered in the car-body design and verification, in pursuit of further weight reductions, as it now happens in aeronautic design

Steel sheets for car bodies (I)

Desired properties

Higher strength
→ lower weight → { ***Lower fuel consumption***
Less pollution (Euro 4 – 5 ...)
Increased load (commercial vehicles)
Lower cost

Plastic energy absorption → *car-crash safety*

Fatigue endurance → *ordinary car service*

Ductility, weldability → *production processes*

Steel sheets for car bodies (II)

Most common overall production cycle

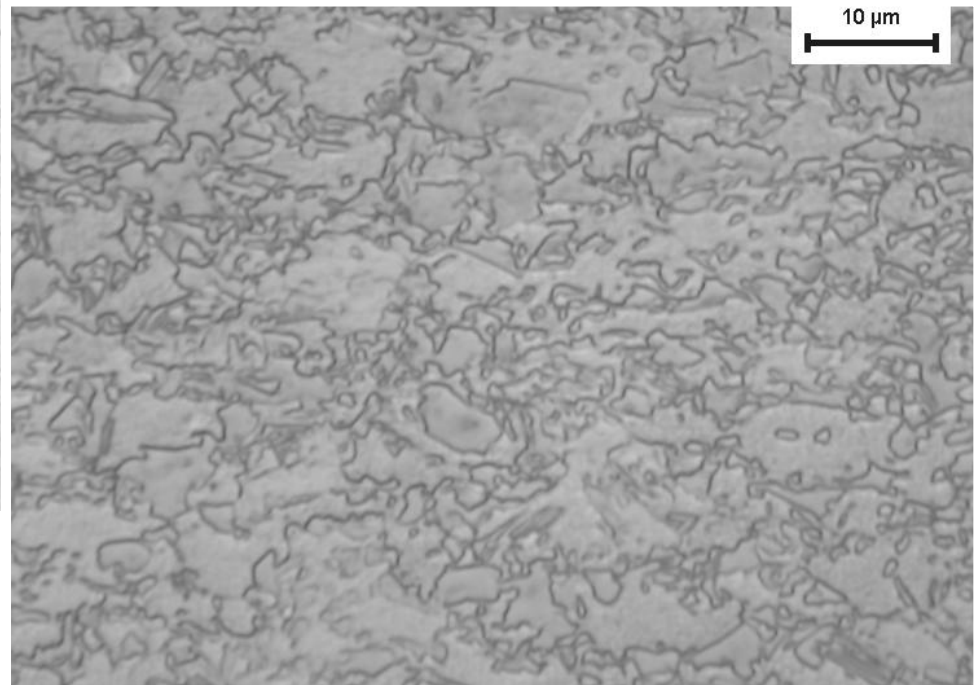
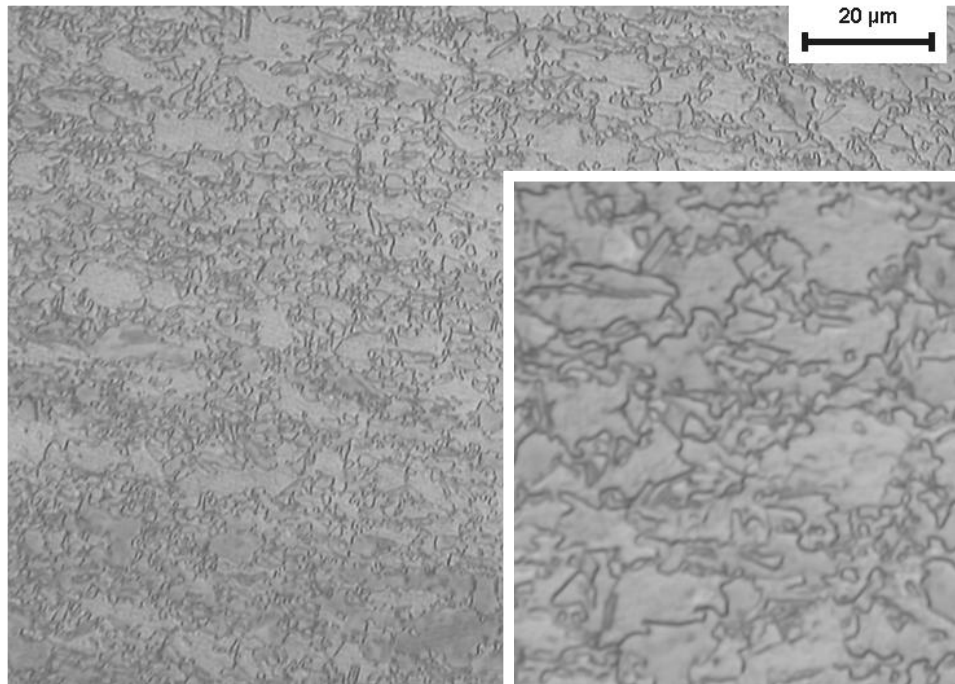
- High-strength weldable steel sheets are made by:
 - continuous casting
 - hot rolling
 - cold rolling
 - continuous final heat treatment
 - protective coating (Zn)
- Sheets are cold formed to produce car body parts
- Car bodies are assembled by resistance spot welding

Examined *Dual Phase (DP)* steel

- widely used
- low alloy, **ferrite and martensite** microstructure
- made by **intercritical annealing and quenching** after cold rolling

OES, Wt. %

| | |
|-----------|--------------|
| C | 0.18 |
| Mn | 2.3 |
| Cr | 0.50 |
| Si | 0.18 |
| Al | 0.034 |
| Nb | 0.025 |
| Ni | 0.015 |

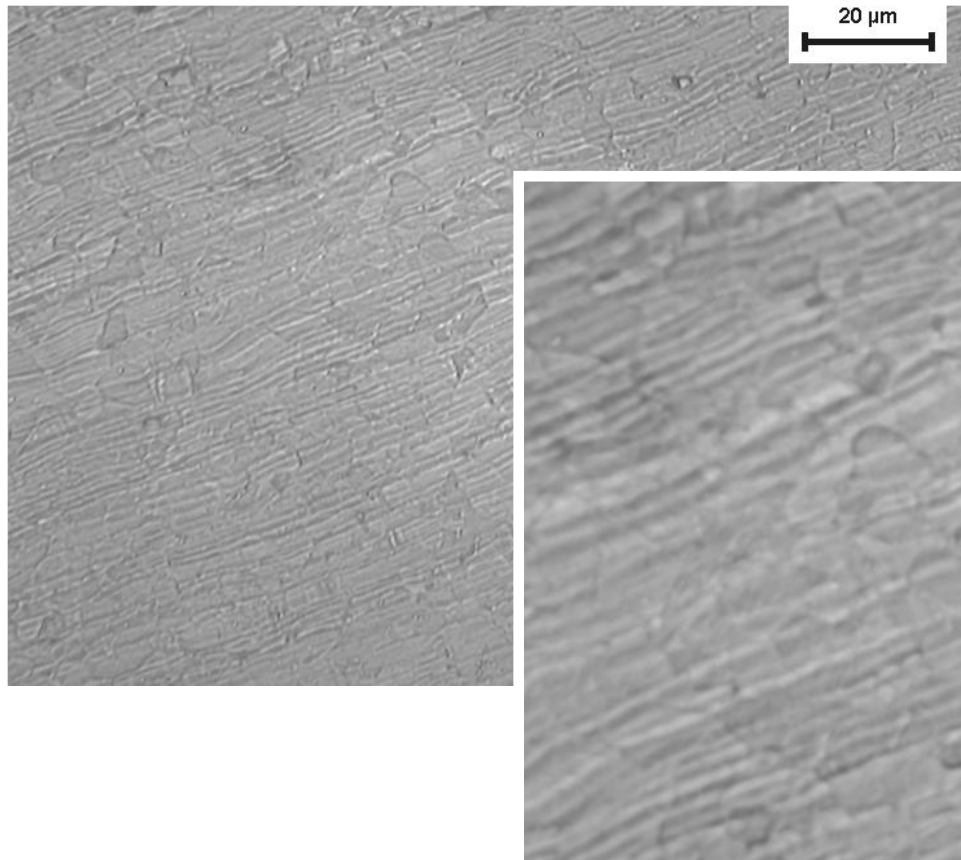


Examined **TWIP** steel

- not yet widely used
- ductile, high-Mn austenite strengthened with solute C
- **TW**inning **I**nduced **P**lasticity (**TWIP**) effect

OES, Wt. %

| | |
|-----------|-------------|
| C | 0.65 |
| Mn | 18.3 |
| Al | 1.5 |
| Ni | 0.41 |
| Si | 0.05 |
| Cu | 0.05 |
| V | 0.04 |
| P | 0.02 |
| S | 0.01 |



Resistance spot welding of **TWIP** steel sheets (I)

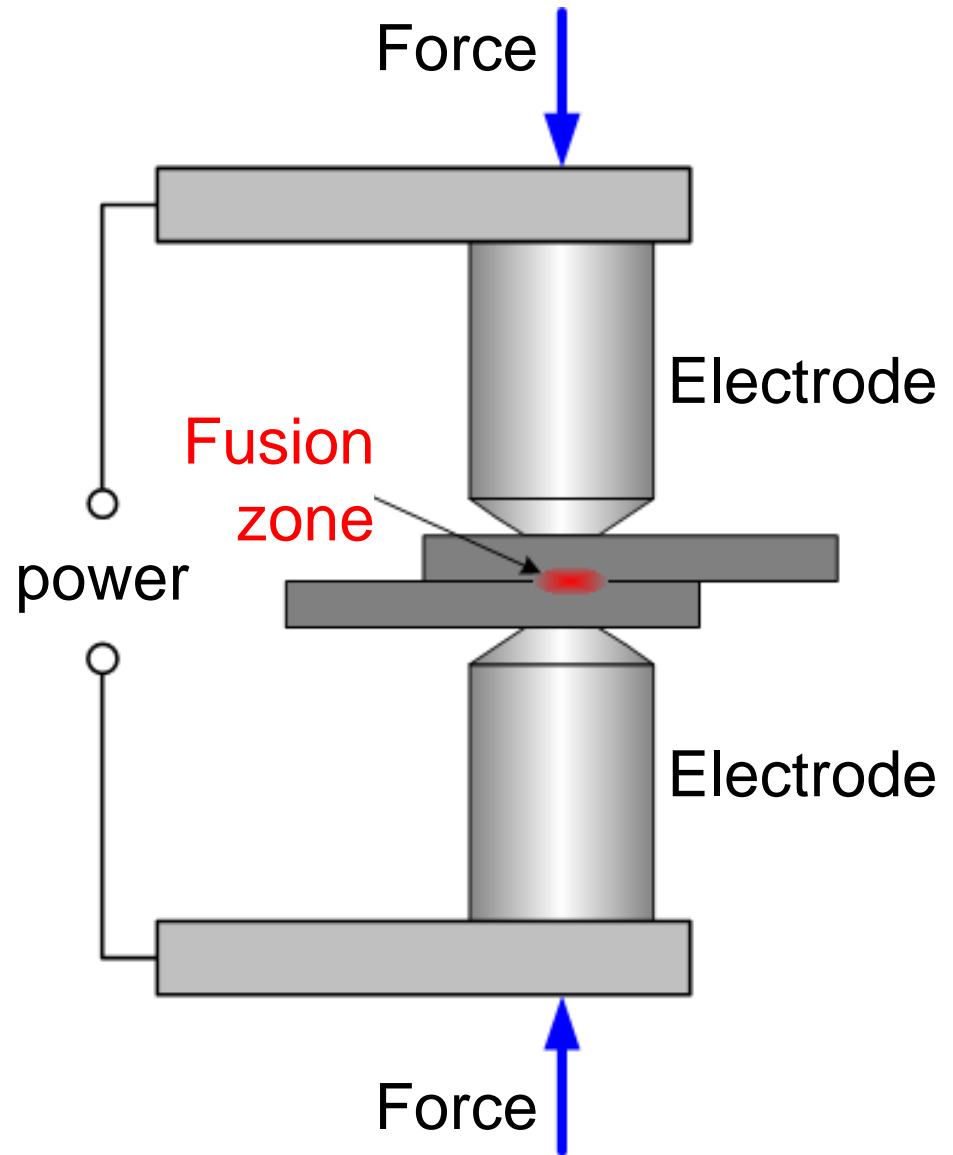
process parameters

Spot radius: 3 mm

Force: 3.5 kN

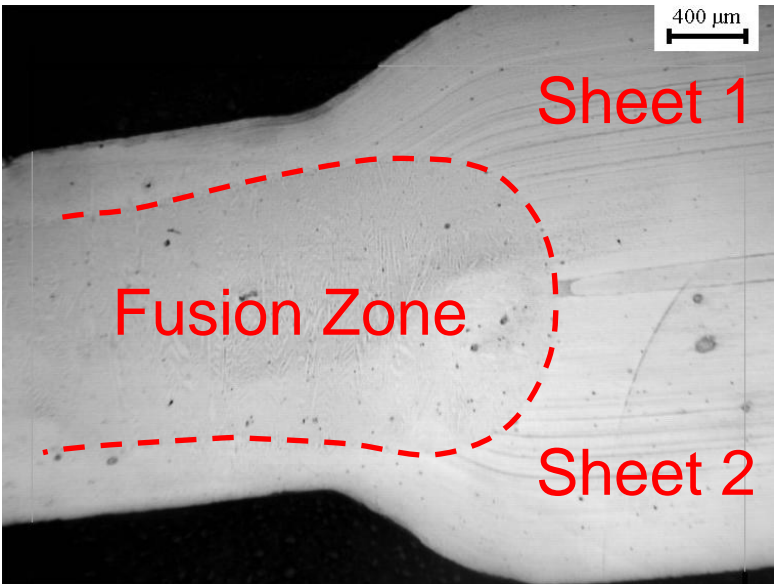
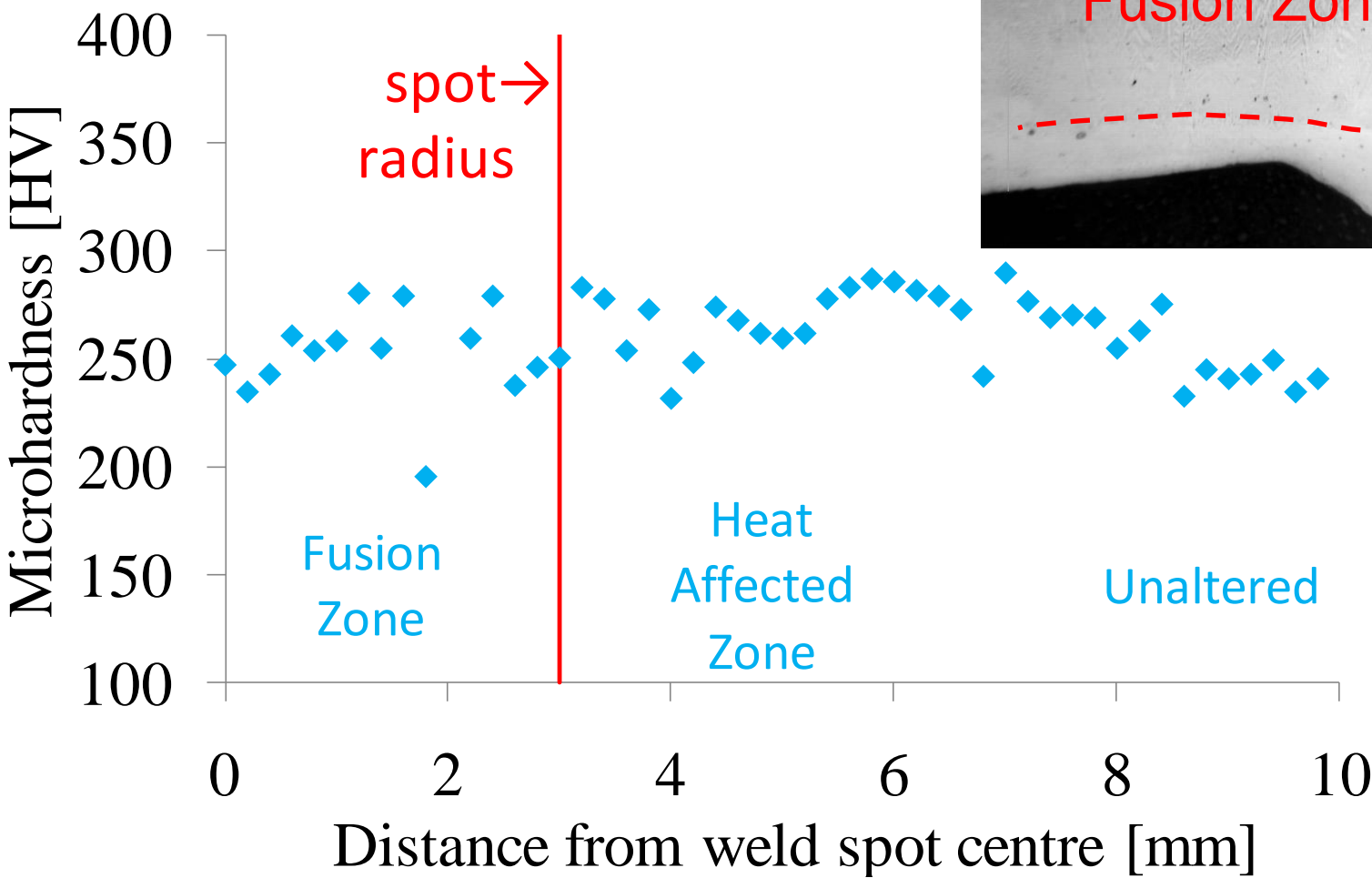
Time: 260 ms

Current: 7 kA



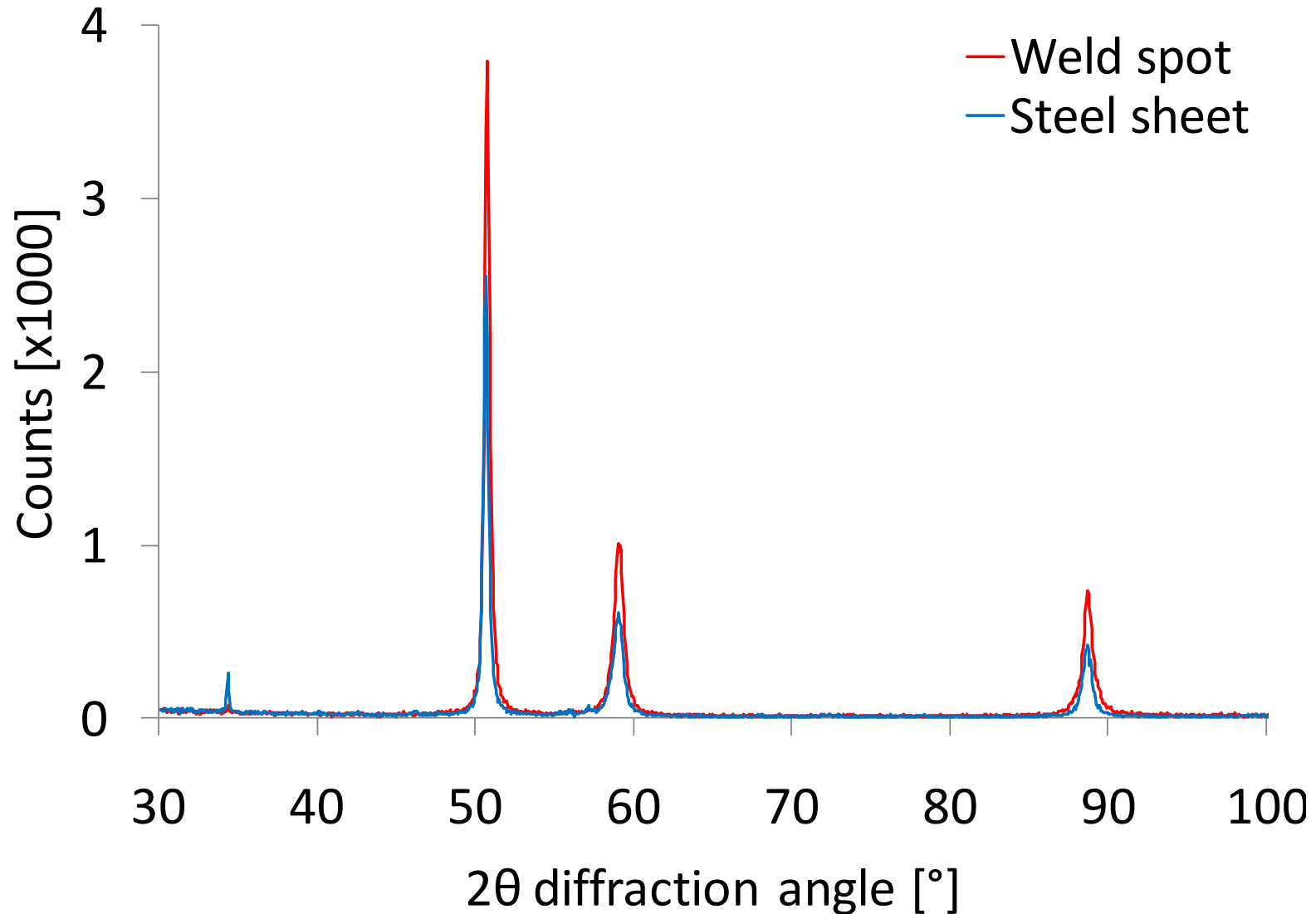
Resistance spot welding of TWIP steel sheets (II)

microhardness (no variations)

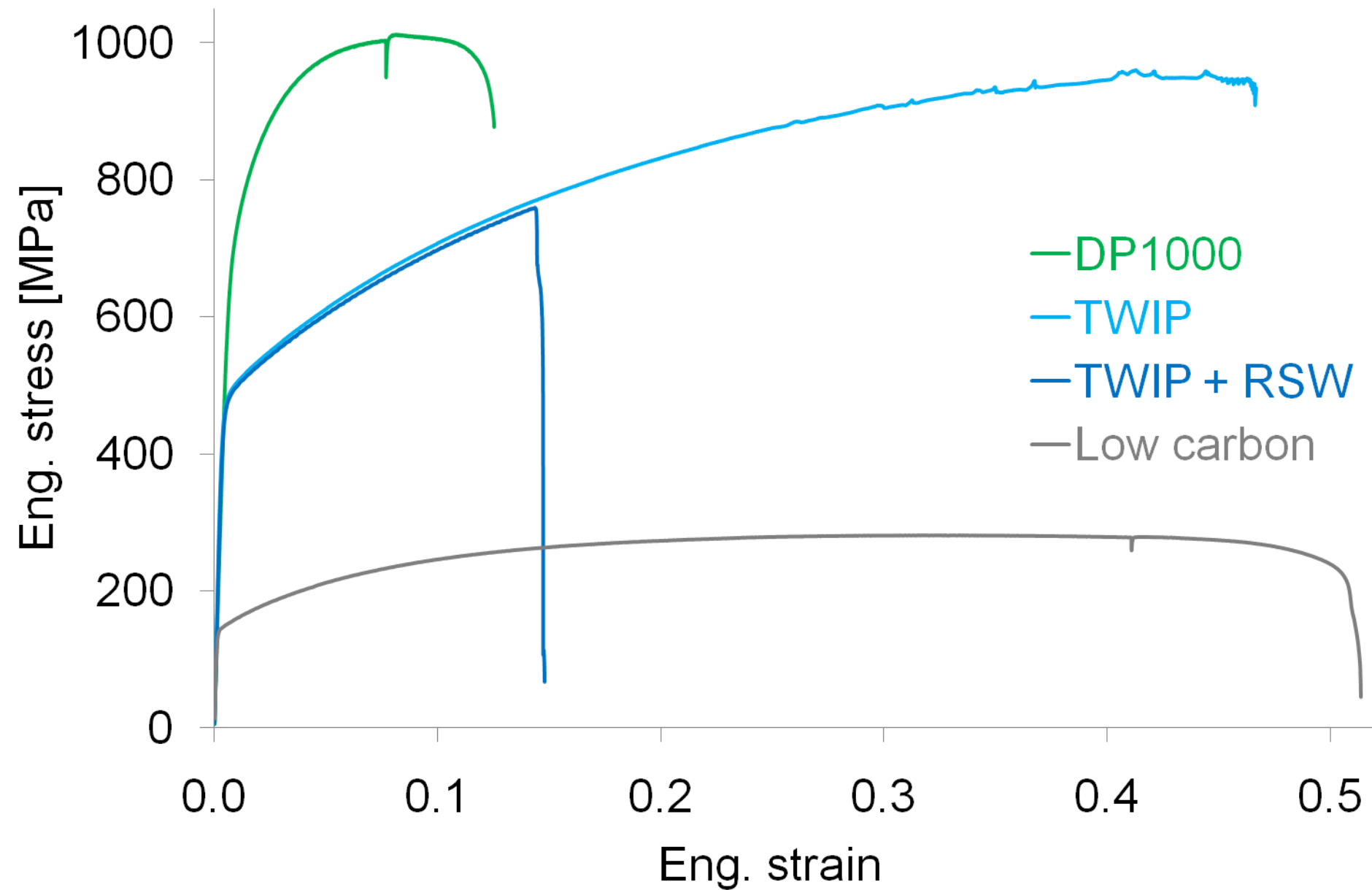


Resistance spot welding of TWIP steel sheets (III)

X-ray diffraction (austenite only)



Tensile curves



S-N fatigue - procedures

- ❖ 20 mm wide, full thickness tensile specimens
- ❖ constant load amplitude fatigue tests
- ❖ **load ratio ≈ 0** (minimum load = 50 N)
- ❖ 10^6 cycles fatigue limit (σ_D), **staircase method**

DP1000

- as-fabricated (with Zn coating)

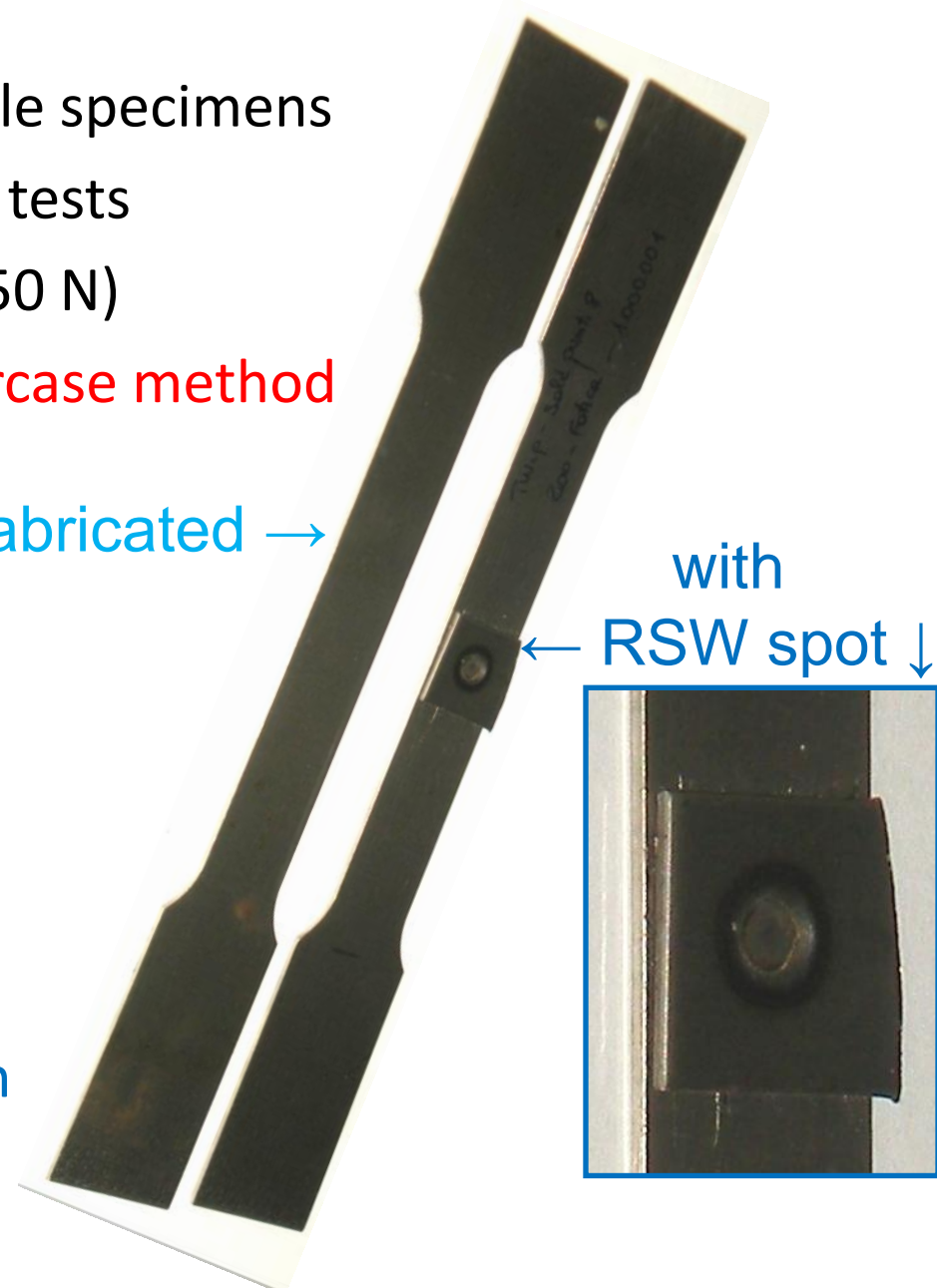
TWIP

- as-fabricated (uncoated)
- with **one RSW spot** at mid-length (joining a 20 mm sheet square)

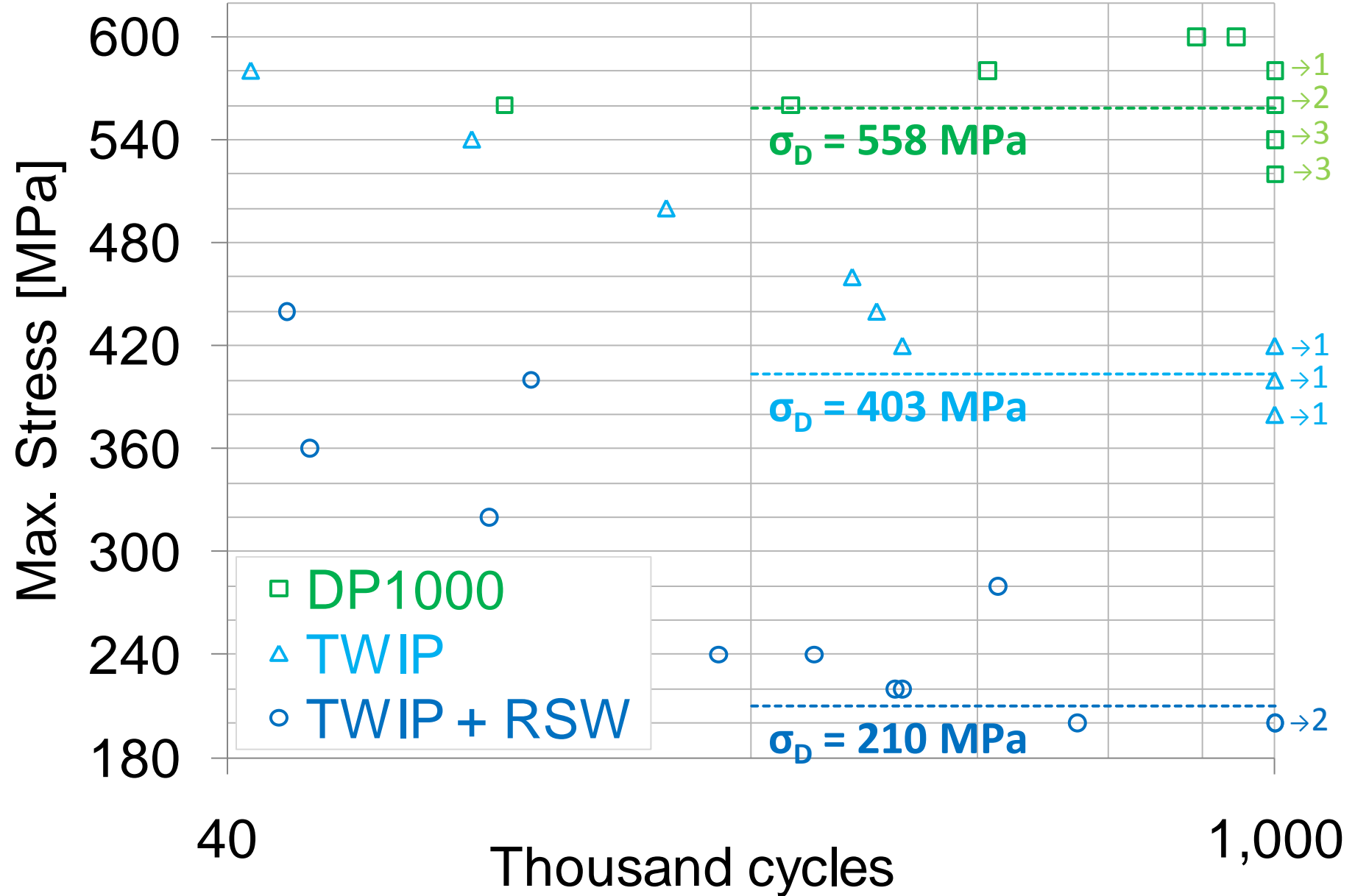
As-fabricated →

with

← RSW spot ↓

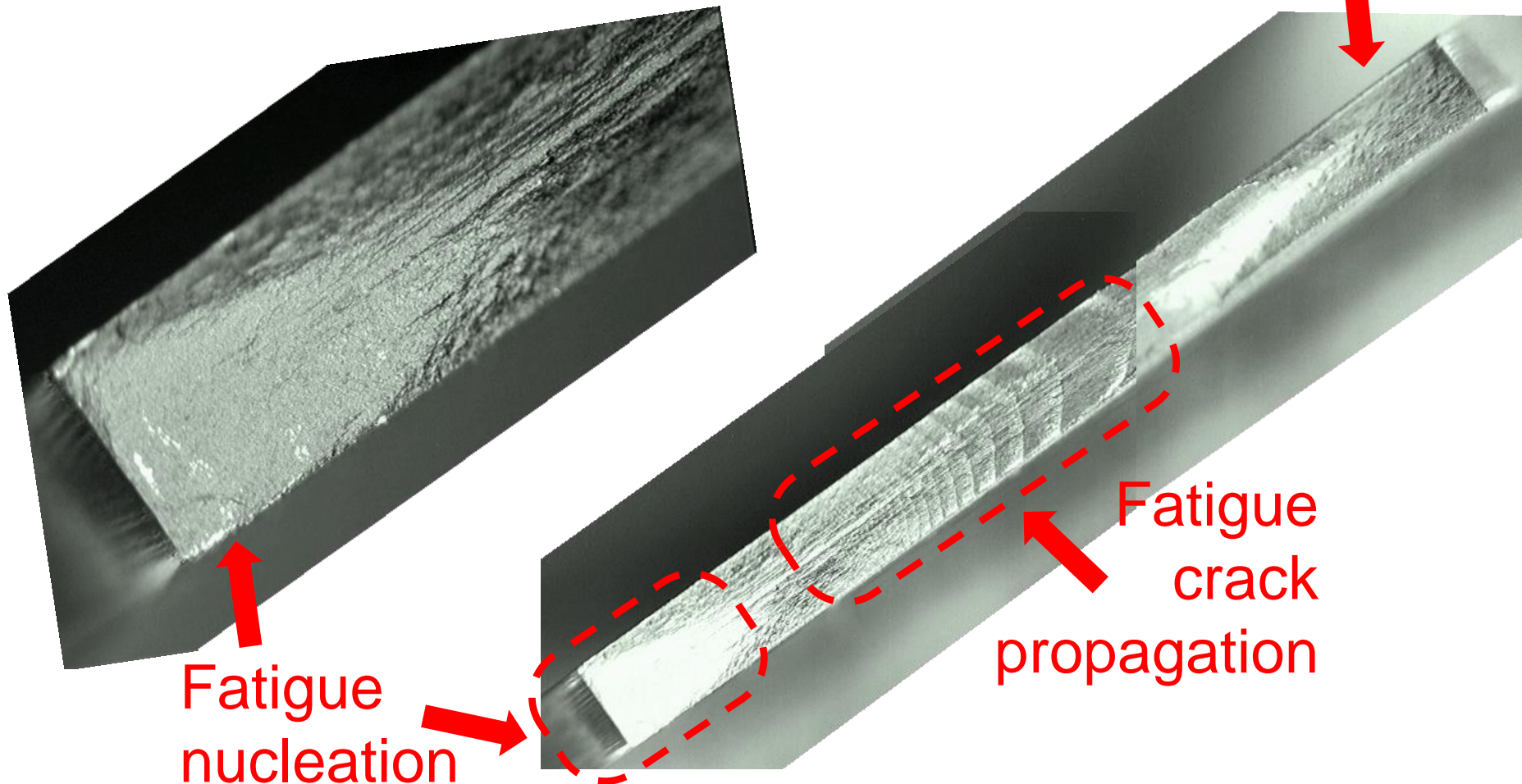


S-N fatigue - results



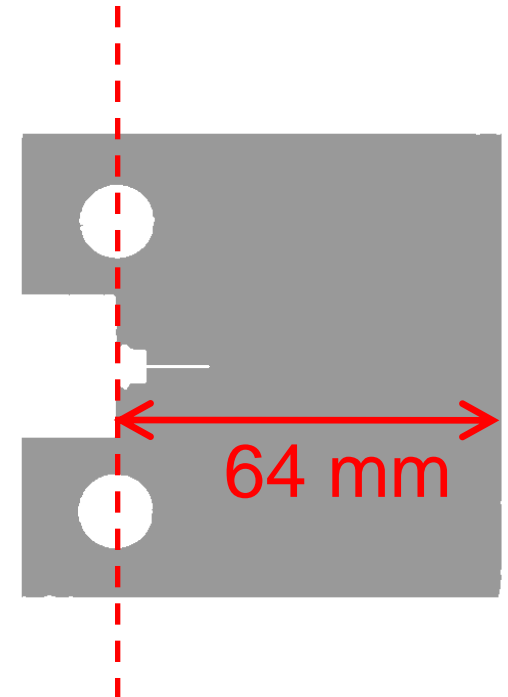
S-N fatigue – optical fractography

DP1000, $\sigma_{\max} = 600$ MPa,
888,842 cycles

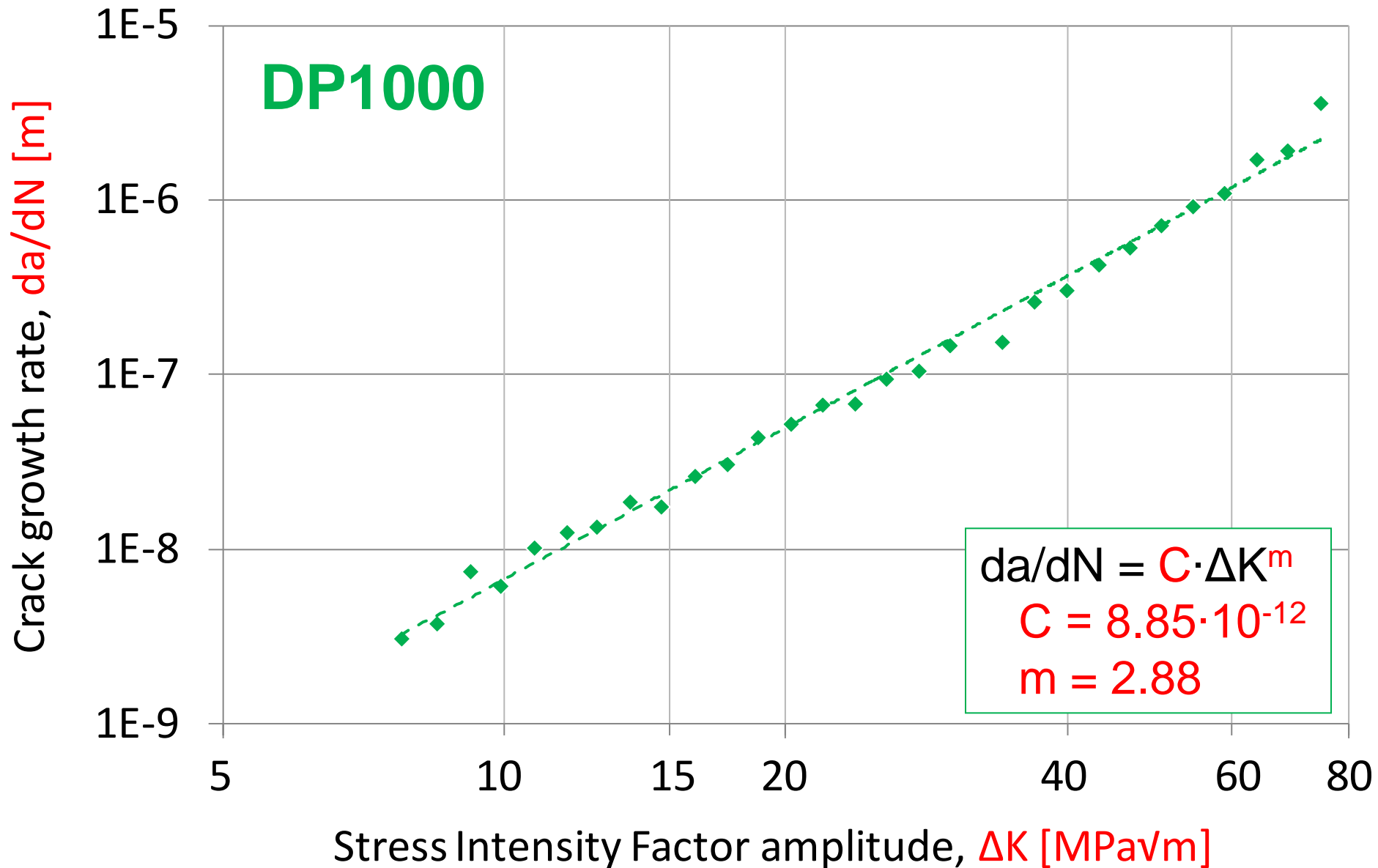


Paris fatigue - procedure

- ❖ polished **Compact Tension** (CT) specimens
- ❖ width **$W=64$ mm**, thickness **$B=1.7$ mm**, **$B/W \approx 1/38$**
- ❖ pre-cracking & fatigue crack growth as per ASTM E647
- ❖ **ΔK -increasing** procedure:
 - load-controlled fatigue steps
 - ≈ 0.3 mm crack growth per step
 - $\approx 8\%$ ΔK increase between steps
- ❖ **Load ratio = 0.1**
- ❖ Optical crack-length measurements



Paris fatigue - results



Conclusions & Future Work

- ❖ The TWIP steel (0.65% C, 18% Mn, 1.5% Al) exhibits remarkable UTS (≈ 950 MPa) and ductility ($\approx 50\%$), but a lower fatigue limit (403 MPa at 1 million cycles) than a dual phase steel with similar strength
- ❖ RSW welding spots greatly reduce the TWIP steel strength, ductility, and fatigue resistance, even if the weld microstructure is similar to the base metal
- ❖ A Paris plot was successfully obtained for a dual phase steel sheet, notwithstanding the quite reduced thickness
- ❖ Further tests are needed for a thorough characterization and comparison of the examined steels

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